NASA Conference Publication 2392

Microgravity Polymers

Proceedings of a workshop held
in Cleveland, Ohio
May 9, 1985

NASA

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Proceedings of a workshop sponsored by the
NASA Lewis Research Center
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PREFACE

A one-day interactive workshop considering the effects of gravity on polymer materials science was held in Cleveland, Ohio, on May 9, 1985. The workshop was organized by Dr. James K. Sutter of the Materials Division and Dr. Richard W. Lauver of the Space Experiments Office. The able support of Drs. Eli Pearce, Jack Koenig, and James Caruthers in the moderation and facilitation of the discussions and the dedication of Drs. Mary Ann Meador, Gary Roberts, and Ken Bowles in auditing and recording the proceedings are gratefully acknowledged. Logistic support was provided by Shelly White of the Materials Division and by the Conferon Company. The lecture series was coordinated by Dr. Ruth Pater.

Seventy representatives from academia, industry, and government participated in the workshop. The program included introductory overviews by NASA representatives, a technical presentation on transport phenomena in microgravity, and a description of a recent flight experiment. Parallel discussions were conducted in three disciplinary working groups: polymer chemistry, polymer physics, and polymer engineering. The discussions were wide ranging and enthusiastic, and the concluding summaries highlighted a number of significant topics for further consideration.

SUMMARY OF LEWIS MICROGRAVITY POLYMER WORKSHOP

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National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

The advent of frequent and reliable access to near Earth orbit via the Space Transportation System presents to materials scientists a new environment with unexplored possibilities for research. The principal attributes of interest are the low levels of gravitational acceleration and the nearly infinite pumping capability at low pressures. The potential implications of conducting experiments in which gravity is a variable have inspired scientists in many fields to consider more carefully the effects of gravity on many phenomena such as solidification, critical phenomena, combustion, and electrophoresis that are complicated (or dominated) by gravity-driven transport on Earth.

The potential utility of processing materials in the absence of gravity-driven convection has prompted several studies of interest to the metallurgical, ceramic and glass, electronic, and biological materials communities. However, there has been limited consideration of polymers in the current materials science activity in space. This limited activity (when contrasted with the major importance of polymer materials in our economy) was the primary rationale for convening this workshop. It was believed that bringing together a group of experts in polymer science and technology with people having direct experience with the microgravity science program would stimulate thought in the area of microgravity polymer science. A significant number of the workshop participants had experience in microgravity science and the development and implementation of space experiments. The participation of scientists with realistic perspectives of both the potential benefits of near Earth orbit and the difficulties of carrying out experiments in that environment proved beneficial in many of the discussions.

A substantial package of literature was made available to the early registrants (appendix A) to provide some common ground for consideration prior to the meeting.

WORKSHOP PROGRAM

The program was organized primarily to fulfill the needs of participants having their initial exposure to discussions of microgravity science. Thus a significant amount of time was committed to the discussion of transport phenomena and fluid physics so that all participants might appreciate the importance of these phenomena in the materials processes to be discussed. To scale each working discussion to a reasonable size, the participants were arbitrarily divided into three groups based on broad disciplines (chemistry, physics, and engineering). However, no constraints were imposed on the range of topics to be considered or on the approach to be employed.

INTRODUCTORY REMARKS AND OVERVIEWS

Introductory remarks were presented by Dr. J. Stuart Fordyce, Director of the Aerospace Technology Directorate at Lewis, and program overviews by Dr. Roger K. Crouch, Chief Scientist of the Microgravity Science and Applications Division of NASA Headquarters, and Dr. Fred J. Kohl, Chief of the Microgravity Materials Science and Applications Branch at Lewis.

The keynote address, "Transport Phenomena in Microgravity," was presented by Simon Ostrach, Professor of Mechanical and Aerospace Engineering at Case Western Reserve University. Professor Ostrach has an extensive background in fluid mechanics and has applied his expertise to fluid flow in microgravity environments and to the fluid mechanics of crystal growth processes. He was ideally qualified to put these transport phenomena in a useful perspective within the context of the workshop. Much of his discussion has been published. In particular, his review of low-gravity fluid flows (Ann. Rev. Fluid Mech. 14, 313-345 (1982)) provides an excellent introduction to the field of low-gravity fluid flows. For this overview he emphasized the fact that going to space does not guarantee a lack of convection. This is due to several considerations including (1) residual accelerations of the environment (i.e., it is low gravity not zero gravity) that result from atmospheric drag, offset of the experiment from the orbiter's center of mass, and "g-jitter" or random fluctuations of the orbiter and its passengers; (2) convections resulting from phenomena such as temperature gradients at free surfaces (Marangoni effects), which have typically been ignored in Earth-bound experiments, and other surface-tension gradient effects that may predominate in space; and (3) thermoacoustic effects that may be active in acoustic levitators. Professor Ostrach also emphasized the need to analyze the material and the process (including the geometry of the sample and container) to predict the relative order of magnitude of the competing transport processes before flying the experiments. He reviewed the dimensionless parameters that permit such analyses to be made and related some examples of the pitfalls of doing materials science in space on the basis of fallacious expectations. The desirability of conducting Earth-based experiments in selected orientations to explore the effects of gravity-stabilized and unstable environments on the fluid system of interest was described with examples chosen from Professor Ostrach's research program. The technical overview was well received and provided a stimulating perspective for the discussion that followed.

Dr. Michael L. Runge, Senior Research Specialist with the 3M Company, presented a brief overview of his company's approach to microgravity science and the potential, from 3M's perspective, for utilizing space experiments in research and development. He described 3M's experience in constructing and flying their initial shuttle experiments. He demonstrated the quality of space-grown crystals in contrast with those grown on Earth with several dramatic microphotographs.

SUMMARY OF WORKSHOP DISCUSSIONS

POLYMER CHEMISTRY

The polymer chemistry discussion group was led by Eli Pearce, Professor of Chemistry at The Polytechnic Institute of New York. Fifteen people participated in the group. To facilitate the discussion, comments were solicited

in four categories: polymerization, organization, separation, and degradation. Highlights of the discussion are given here.

Polymerization Phenomena

Limited coalescence and breakup of emulsions. - The microgravity environment permits better control of droplet size in emulsion polymerization. This has been demonstrated for the manufacture of polystyrene beads with narrow size distribution and may be useful in other polymer systems. The space environment may allow the study of droplet breakup and the coalescence of emulsions for droplet sizes that are unstable in normal gravity. The minimization of convective transport may permit the study of diffusion-controlled processes.

Ionic and radical polymerization in the gas phase. - For ionic polymerization in microgravity charge repulsion would predominate. Thus particles would not settle and a stable suspension of growing molecules could be formed. For radical polymerizations in microgravity there may be effects that control tacticity and polydispersity.

Polymerization of vesicles. - Polymerization in microgravity may create vesicles of more uniform size that would have greater utility as containers for catalysts, drug encapsulation, magnetic particles, etc.

Cage effects. - In radical-initiated polymerization the cage effect should be larger in microgravity; the magnitude of the effect and the polarity of the cage should be affected.

Anionic monodisperse systems. - It may be possible to generate monodisperse systems by anionic polymerization. This might produce more uniform particles than normal-gravity processes. These particles could be functionalized after polymerization to produce a variety of compositions having utility beyond that of uniform size.

Whisker growth. - Less turbulent, potentially diffusion-controlled transport may enhance the growth of structures such as whiskers. This may be desirable for graphite fibers (e.g., 1,8-naphthalenedicarboxylic acid anhydride could be pyrolyzed in microgravity to get more perfect alignment).

Organization in Polymer Liquids

Liquid crystalline polymers. - It may be possible, in a microgravity environment, to achieve enhanced ordering in thermotropic systems.

High-yield heterogeneous catalysts. - It may be possible in microgravity to synthesize catalysts with more uniform cavities.

Film formation by electrodeposition or emulsion. - The microgravity environment may permit a more stable emulsion. This might permit formation of a more uniform protective film for improved corrosion resistance.

Casting of phase-separated systems. - The minimal convection and relative strength of interfacial forces in the microgravity environment may permit the generation of new morphologies.

Separation Science and Processes

Phase separation of polymers. - In a microgravity environment both surface and bulk properties are important. It may be possible to form systems that are intermediate between colloidal suspensions and bulk polymers. This may improve understanding and permit evaluation of previously untested compositions in systems such as high-impact polystyrene, which exhibits phase separation at about 23-percent conversion in normal gravity.

Inverse-column chromatography. - Enhanced effects of surface energy and capillarity in microgravity may permit larger scale separations and molecular weight determinations by inverse-column chromatography.

Porosity control. - Processing in the microgravity environment may permit better control of porosity in polymeric substrates for gel permeation chromatography, liquid chromatography, catalytic supports, and electrophoresis.

Degradation Phenomena

Flocculation of colloidal solutions. - The absence of sedimentation in the microgravity environment will permit studies of the contribution of Brownian diffusion to the stability of large-particle colloids in the absence of agitation.

Pyrolysis. - The minimal convection in the microgravity environment may be useful in the production of graphite and silicon carbide.

The major points selected by the discussion group are summarized in table I.

POLYMER PHYSICS

The polymer physics discussion group was led by Jack Koenig, Professor of Polymer Science at Case Western Reserve University. Thirteen people participated in the discussion. The discussion began by considering selected properties of polymers that make them unique and useful materials and selected properties of near Earth orbit that might be useful in polymer science.

The following properties are unique to polymers or are more complex in polymers than in nonpolymeric materials.:

(1) High molecular weight and wide distribution of molecular weights
(2) Viscosity and flow properties (controllable over a wide range by varying the molecular weight)
(3) Critical phenomena (phase separation and solidification)
(4) Surface properties
(5) Morphology
(6) Microstructural changes (conformation and segregation)
(7) Solubility

The following properties are unique to the microgravity environment and may be utilized in polymer science experiments:

(1) Reduction in buoyancy-driven convection
(2) Reduction in sedimentation

In the context of these unique attributes several aspects of polymer microgravity science and technology were discussed. The highlights of this discussion are given here.

Surface and Interface Properties

Less settling in microgravity would make it easier to study the interface in colloids. Interfacial phenomena are important but very complex. The reduced turbulence in microgravity may have a large effect.

Polymer Blends

In general the phase with high viscosity or high concentration becomes the continuous phase. The morphology resulting from intermediate values of viscosity is not well defined, and microgravity may affect the morphology.

Microgravity may result in a more uniform distribution of the dispersed phase.

The microgravity environment may be useful for studying kinetics in interpenetrating polymer networks (IPN's).

Containerless Processing

Impurities from reactor walls are known to exist in polymers. These impurities may act as nucleation sites for crystallization. Containerless processing may result in ultrapure polymers that can be quenched to the amorphous state without crystallization.

Rationale for Microgravity Effects in Polymers

The gravitational force is long range, but the polymerization is short range. Therefore microgravity will probably affect polymerization through convection rather than through direct interaction.

Heat transfer is important and will be affected by microgravity through the magnitude of convection.

Microgravity allows a spatial distribution of heat and composition that may not be stable in the larger, normal-gravity field (possible applications to layered structures).

It would be of interest to use non-Newtonian polymeric fluids in fluid flow experiments.

The major points selected by the discussion group are summarized in table II.

POLYMER ENGINEERING

The polymer engineering discussion group was led by James Caruthers, Professor of Chemical Engineering at Purdue University. Seventeen people participated in the discussion. A number of possible applications of the

low-gravity environment for the study of polymer engineering and processing phenomena were discussed. The highlights of these discussions are outlined here.

Suspension Polymerization

The breakup of suspended droplets of polymer and monomer solutions by pressure waves might usefully be studied in low gravity since single droplets might more easily be isolated for study. Some applications for which this technology would be beneficial are

(1) Drop breakup during processing
(2) Microencapsulation
(3) Fuel atomization
(4) Phase transfer catalysis

Phase-Separated Materials

Interfacial phenomena can dramatically affect the performance of a polymer product. The enhanced effects of interfacial forces in a low-gravity environment might enable improved study and exceptional control of phase-separated materials. Some areas for consideration are

(1) Fundamental studies of interfacial phenomena
(2) Control of domain size
(3) Use and control of surface energy

Improved understanding in these areas could affect technology related to the production of rubber-modified polymers and the production of microporous beads for chromatography and drug release.

Inorganic Polymers

The production of high-strength ceramic components from sols and powders is complicated by the tendency of these dense materials to sediment and aggregate in normal gravity. It may be possible to generate more uniform powders or highly ordered suspensions of inorganic materials in a low-gravity environment, and this might lead to improved understanding of these materials and processes.

Gas-Phase Polymerization

Accessible conditions for gas-phase polymerization in normal gravity are substantially constrained by the flow rates required to fluidize the solid catalyst particles and by the distribution of polymer particles as they grow. The low-gravity environment offers a unique capability to study several aspects of these systems, such as

(1) Fundamental studies of polyolefins: a greater number of chemical systems should be accessible in space.

(2) Distribution of catalysts (particle breakup, size distribution effects, etc.)

(3) Attrition of catalysts. The ability to polymerize at much lower flow rates in low gravity should minimize the attrition of catalyst particles.

(4) Gas velocity. In low gravity flow rate can become an experimental variable that is independent of the materials involved.

Flocculation

The microgravity conditions may be useful in studying colloidal polymer systems that aggregate via flocculation and that are difficult to handle in normal gravity. One might consider

(1) Mechanism (flocculation versus settling)
(2) Stabilization of selected structures

Better understanding of such phenomena might permit control of bridge or network structure and steric stabilization of such systems.

Ultrathin Films

Apparatus boundaries are an important factor in the formation of ultrathin films (such as Langmuir-Blodgett films). Experiments in a microgravity environment may be useful in assessing these effects.

Mechanics of Manufacturing and Repairing Composite Structures in Space

The possibility that large space structures will incorporate polymer composite materials suggests a requirement for technologies related to the construction and repair of such structures in space. The development of engineering experience and improved science and technology will be needed in areas such as

(1) Adhesion (improved materials with necessary handling and cure characteristics)
(2) Pressurization (engineering requirements for aligning, supporting, and pressurizing large adherends)
(3) Aggressive environment (development and evaluation of materials compatible with the orbital environment (ultraviolet radiation, oxygen atom flux, temperature extremes, etc.)

Non-Newtonian Rheology

The potential for handling, in microgravity environments, material systems that are typically unstable or short lived in normal gravity may make it possible to study such systems and phenomena as

(1) Multiphase dispersions
(2) Density-induced changes
(3) Concentration effects
(4) Particulate-filled emulsions

The major points selected by this discussion group are summarized in table III.

CLOSING REMARKS

The microgravity polymer workshop was concluded on a positive note. The discussions were enthusiastic and most were well focused and informative. Many optimistic comments were received from participants and observers.

Several legitimate technical areas were identified for further consideration and many stimulating and enthusiastic people were made aware of the possibilities for doing useful science in a microgravity environment. All participants and other interested parties are encouraged to consider direct involvement in the microgravity science program. To facilitate that involvement and to stimulate further thought, we have included the names of key contact points within Lewis and NASA microgravity science programs (appendix B) and information on the major facilities available at Lewis to support microgravity research (appendix C).

APPENDIX A

LITERATURE SUPPLIED TO PARTICIPANTS

The following reference material was made available to workshop participants. The references were selected to stimulate interest in the field, to provide selected introductory information, and to assist in accessing the available literature.

Gelles, S.H., et al.: Materials Science Experiments in Space. NASA CR-2842, 1978.

Herschkowitz-Kaufman, M.; Nicolis, G.; and Nazarea, A.: Influence of Gravity on Pattern Formation in Nonequilibrium Systems. Z. Flugwiss. Weltraumforsch., vol. 2, no. 6, Nov.-Dec. 1978, pp. 379-386.

Kondepudi, D.K.: Influence of Gravitation on the Bifurcation of Steady States in Chemical Systems. Z. Flugwiss. Weltraumforsch., vol. 3, no. 4, July-Aug. 1979, pp. 246-255.

Malmejac, Y.: Challenges and Prospectives of Microgravity Research in Space. Materials Processing in Space, Bonnie J. Dunbar, ed., American Ceramic Society, Columbus, OH, 1983, pp. 215-339.

Moldover, M.R., et al.: Gravity Effects in Fluids Near the Gas-Liquid Critical Point. Rev. Mod. Phys., vol. 51, no. 1, Jan. 1979, pp. 79-99.

Ostrach, S.: Low-Gravity Fluid Flows. Annual Review of Fluid Mechanics, Vol. 14, M. Van Dyke, J.V. Wehausen, and J.L. Lumley, eds., Annual Reviews Inc., Palo Alto, 1982, pp. 313-345.

Ostrach, S.: Fluid Mechanics in Crystal Growth - The 1982 Freeman Scholar Lecture. J. Fluids Eng., vol. 105, no. 1, Mar. 1983, pp. 5-20.

Pentecost, E.: Materials Processing in Space Bibliography. NASA TM-82466, 1982.

Pentecost, E.: Materials Processing in Space Bibliography - 1983 Revision. NASA TM-82507, 1983.

Pentecost, E.: Microgravity Science Applications Bibliography - 1984 Revision. NASA TM-86651, 1984.

APPENDIX B

POINTS OF CONTACT AND MODES OF INTERACTION WITH NASA

Responsibility for the microgravity materials science program within NASA resides in the Office of Space Science and Applications (Code E). The program is administered by

Microgravity Science and Applications Division
Code EN
NASA Headquarters
Washington, DC 20546

(202)453-1490

Mr. Richard E. Halpern, Director
Dr. Roger K. Crouch, Chief Scientist

Information concerning formal interaction with the program and review of technical proposals is handled through this office.

The program is implemented and detailed technical support is handled through regional NASA centers. The major activities are at

Lewis Research Center
Cleveland, OH 44135

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Langley Research Center
Hampton, VA 23665

Lyndon B. Johnson Space Center
Houston, TX 77058

Jet Propulsion Laboratory
Pasadena, CA 91109

At the Lewis Research Center the principal contacts are

William J. Masica, Chief
Space Experiments Office
Mail Stop 500-205
(216)433-2864

Dr. Fred J. Kohl, Chief
Materials Science and Applications Branch
Mail Stop 500-205
(216)433-2866

Salvatore J. Grisaffe, Chief
Materials Division
Mail Stop 49-1
(216)433-3193

Additional contacts are listed with the specific facilities described in appendix C.

Individual experimenters or larger groups and companies can interact with NASA in the microgravity materials science program in many ways. At the individual level these include informal interactions and inquiries (encouraged during the formative stages of any programs) and formal technical proposals for grant or contract support. On a larger scale the interactions can extend to guest investigator programs, joint endeavor agreements, and other legal agreements that commit both NASA and the company to support of the proposed flight program. Interested parties are encouraged to explore any avenues that appear to meet the requirements of specific technical programs.

APPENDIX C

FACILITIES AT LEWIS FOR MICROGRAVITY RESEARCH

The Lewis Research Center operates several research facilities dedicated to the support of microgravity science. These facilities are accessible to program participants. The Center address and telephone number are

NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

(216)433-4000

The names and telephone numbers of the principal points of contact are given here.

DROP TOWERS
(Lou Corpas, (216)433-2451)

The Lewis Research Center has two major drop tower facilities. The largest provides 5 seconds of low gravity during a 147-meter drop. The smaller provides 2.2 seconds of low gravity during a 30-meter drop. Both facilities are staffed by experienced personnel who provide operational support and design and construct the experiment packages. These facilities are used routinely for experiments that have a time scale compatible with the free-fall times available. Many fluid flow studies and selected combustion studies have been implemented in both drop towers.

LEWIS LEARJET
(Fred J. Kohl, (216)433-2866)

High-speed aircraft, such as the NASA Lewis Learjet, can provide 10 to 20 seconds of low gravity during a carefully flown Keplerian trajectory. This aircraft can support large-scale experiments and those requiring operator intervention. The low-gravity trajectory can be repeated several times on a single flight, and the gravity level can be selected within a useful range of both high and low accelerations. This facility provides an accessible, low-cost approach to development and implementation of low-gravity experiments.

MICROGRAVITY MATERIALS SCIENCE LABORATORY
(Leslie A. Greenbauer-Seng, (216)433-5013)

The Materials Division of the Lewis Research Center operates a laboratory dedicated to the support and implementation of microgravity materials science and materials processing experiments. The facility includes hardware and systems that are functional duplicates of the current generation of flight hardware for conducting solidification studies as well as the necessary metallographic equipment for sample preparation and preliminary analysis. Extensive metallographic, micrographic, and spectral analysis facilities are accessible at the Center. The laboratory also provides a 5-meter vacuum drop tube with an electromagnetic levitator for insertion of high-temperature metal samples. This drop tube has substantial instrumentation for determining the temperature of the sample during the free-fall experiments. The laboratory has dedicated

computer capabilities for experiment control and data reduction and has direct access to the Center computer network for more extensive analyses.

FLUIDS AND COMBUSTION LABORATORY
(Jack A. Salzman, (216)433-2868)

The Space Experiments Office at the Lewis Research Center operates a laboratory dedicated to the development and implementation of experiments to elucidate the effects of gravity on fluid systems and combustion processes. The laboratory includes optical and spectral instrumentation and facilities for studying fluids, such as interferometric and holographic imaging systems and light-scattering spectrometers. The facility has dedicated data systems to support internal requirements for instrument control and data handling and has access to the central computer capabilities of the Center for more substantial computational requirements. Clean-room capabilities exist for the handling of flight-quality hardware, and an experienced staff supports the laboratory.

APPENDIX D

ABSTRACTS OF 1984-85 LEWIS POLYMER LECTURE SERIES

A series of invited lectures was held at the Lewis Research Center for the information of Lewis personnel and in preparation for this workshop. Brief abstracts of the lectures are given here.

1. Speaker: Dr. Jack Koenig, Professor of Polymer Science at Case Western Reserve University
   Date: December 17, 1984
   Title: Improved Polymer Composites Using Microgravity Conditions
   Abstract: This talk described research directed toward the preparation of improved high-performance polymer composites by using microgravity conditions. It was suggested that the microgravity conditions should remove a systematic structural gradient in the interfiber region arising from the gravity-induced migration of polymerizing molecules. The rate of sedimentation of the polymerizing species in the gravity field depends on the molecular weight of each species. Molecular weight can range from the single monomer to 10 000 or 20 000 reacted monomer units in a single particle. It was predicted that this sedimentation-induced gradient of molecular weights would favor the chemical reaction between higher molecular weight species rather than the preferred homogeneous reaction. The predicted result under normal gravity is an asymmetric molecular structure with a molecular weight/structural gradient from the polymerization initiation site in the direction of the gravity field. From a macroscopic point of view these structural defects have deleterious effects on the properties. Under microgravity conditions the sedimentation effects will be minimized and these structural defects might be removed. In this manner improved high-performance composites may be prepared. This talk outlined computer simulation experiments that would attempt to estimate the structure and properties of the polymer network in the presence and absence of gravity. Experiments that might be easily carried out were proposed for the NASA space shuttle. Successful microgravity experiments may validate the role of structural gradients induced by gravity and redirect the approach to the processing and fabrication of polymer composites in the presence of gravity. Ultimately these results could lead to basic improvements in high-performance fiber-reinforced composites for military and civilian use.

2. Speaker: Dr. James Caruthers, Professor of Chemical Engineering at Purdue University
   Date: December 19, 1984
   Title: Opportunities of Microgravity Research for Prediction of Drop Breakup in Industrial Polymerization Processes
   Abstract: Standard dimensional analysis procedures were applied to the flow of polymeric materials in order to determine when gravitational effects will be important. It was shown that, because of the extremely high viscosity of polymer melts and solids, gravity should be important only for monomers and polymer solutions. A specific microgravity experiment to elucidate the drop breakup mechanism in suspension polymerization was described. Suspension polymerization is the largest-volume commercial polymerization process, and the breakup of monomer and polymer solution droplets is the most poorly understood aspect of that process. Prediction of drop breakup, in the turbulent flow that is present during suspension polymerization, is of fundamental scientific interest and would facilitate the production of new and commercially important polymeric materials.

3. Speaker: Dr. James White, Professor of Polymer Engineering at Akron University
Date: January 11, 1985
Title: Microgravity and Polymer Melt Rheology and Processing
Abstract: The characteristics of the polymeric state of matter and the basic methods of rheological measurement of polymer melts were reviewed, and the areas where microgravity may be helpful were described. This largely concerns elongational flow, where sagging is a problem in normal-gravity experiments. Interfacial tension should also be more readily measured in the absence of normal gravity. The basic methods of polymer processing were summarized. Microgravity may be of importance in stretching crystallizable polymers in the melt state and in crystalline growth and foaming mechanisms.

4. Speaker: Dr. Herman Mark, Professor Emeritus at Polytechnic University of New York
Date: January 24, 1985
Title: New Trends in Polymer Science and Engineering
Abstract: At the beginning the synthetic polymers were pioneered and developed in close contact with their natural counterparts (fibers, membranes, rubbers, and resins) and started to make substantial contributions to such industries as textile, paper, packaging, rubber, and plastics. Later systematic studies of structure-to-property relationships opened interesting vistas for a substantial extension of such properties as rigidity, softening range, glass transition point, conductivity, and range of rubberiness. At the same time significant improvements in synthesizing macromolecules made it possible to prepare a great variety of new materials with an astounding range of physical and chemical properties. These materials are being studied, and it appears that they will make substantial contributions to those industries that concentrate on progress in transportation, communications, the construction of buildings, plants, highways, and pipelines, and off-shore oil production facilities. There are essentially two causes for progress in our field of interest: new materials and processing techniques, and new demands for performance that would open up new uses and new markets. In both respects several new materials and processes promise to reach fruition in the next decade. Electrically conducting and semiconducting polymers are new materials that need additional improvements in stability and processability to usher in a new era of electrical engineering: lighter batteries, smaller losses in electricity transport, less corrosion, and less environmental damage. Improvement of light-conducting polymers will substantially advance the use of light instead of electric current in telephony, telegraphy, television, and other signal transmissions. Results will be lower cost, higher performance, safer practice, and better protection of the environment. More precise control of photopolymerization and photodegradation of macromolecular systems will substantially increase the storage capacity of chips, floppy disks, and other computer components. As our interests more and more expand into space, new and light film- and fiber-forming materials will be needed to more efficiently construct spacecraft, shuttles, and space stations. Metals as heavy as steel or titanium should have no place in space engineering and even aluminum should be replaced by lighter and stronger composites.

5. Speaker: Dr. W. Curtis Conner, Professor of Polymer Science at University of Massachusetts
   Date: February 7, 1985
   Title: Catalyst Preparation and Gas-Phase Polymerization: The Effects of Microgravity
   Abstract: The vast majority of polymer production involves catalysis by heterogeneous (solid) surfaces. As practiced, the processes of catalyst preparation and polymerization are influenced by gravity. Indeed in a microgravity environment unique catalyst systems are possible, and conditions of polymerization are dramatically changed. Both from a practical and a scientific perspective, experiments at reduced gravity would be significant. General aspects of catalysis, catalyst preparation, polymerization, and the symbiotic relationship between these factors were covered. The talk focused on the potential microgravimetric studies that may contribute to our understanding and application of these areas.

6. Speaker: Dr. John W. Vanderhoff, Professor of Chemistry at Lehigh University
   Data: February 8, 1985
   Title: Preparation of Large-Particle-Size Monodisperse Latexes in Space: The STS-3, STS-4, STS-6, and STS-7 Mission Results
   Abstract: The preparation of monodisperse polystyrene latexes larger than 2 micrometers in diameter by seeded emulsion polymerization is difficult owing to the creaming and settling of the particles and their sensitivity to mechanical shear. Preparation in microgravity obviates the creaming and settling and allows agitation just sufficient for good heat transfer and mixing. Large-particle-size monodisperse latexes were prepared on five STS missions of the space shuttles Columbia and Challenger in four automated 100-milliliter polymerization reactors. Seven polymerizations carried out on the March 1982 STS-3 mission of the Columbia and on the April 1983 STS-6 and June 1983 STS-7 missions of the Challenger gave monodisperse latexes 5 to 18 micrometers in diameter with narrower particle size distributions than the corresponding ground-based control polymerizations. The 10-micrometer-diameter STS-6 latex has been accepted by the National Bureau of Standards as a standard reference material and hence is the first product made in space. Three polymerizations carried out on the February 1984 STS-11 mission gave monodisperse latexes 18 to 30 micrometers in diameter; measurement of their particle size distributions is in progress. The talk reviewed the results of these experiments.

TABLE I. - SUMMARY OF POLYMER CHEMISTRY DISCUSSION

- Polymerization
  - Limited coalescence
  - Gas-phase polymerization
  - Polymerization of vesicles
  - Cage effects
  - Anionic monodisperse systems
  - Whisker growth

- Organization
  - Liquid crystalline polymers
  - Heterogeneous catalysts
  - Film formation
  - Casting of phase-separated systems

- Separation
  - Phase-separated polymers
  - Inverse-column chromatography
  - Porosity control

- Degradation
  - Flocculation of colloidal solutions
  - Pyrolysis

TABLE II. - SUMMARY OF POLYMER PHYSICS DISCUSSION

Potential for microgravity

- Better understanding of fluid behavior
- Appreciation of role of mixing gradients
- Understanding of critical phenomena
  - Phase changes
  - Phase separation
- Interfacial phenomena
  - Adsorption
  - Surfaces

Selected experiments to consider

- More uniform mixing
  - Initiators and catalysts
  - Blends
  - Determination of surfaces and interfaces

- Stratification
  - Multicomponent systems
  - Multilayered structures
  - Built-in gradients (for membranes)

- Containerless processes
  - Ultrapure polymers
  - Elimination of surface and substrate effects
  - Viscoelastic fluids
  - Morphological modification (homogeneous nucleation)

TABLE III. - SUMMARY OF POLYMER ENGINEERING DISCUSSION

- Suspension polymerization
  - Drop breakup
  - Microencapsulation
  - Fuel atomization
  - Phase transfer catalyst

- Phase-separated materials
  - Interfacial phenomena
  - Domain size
  - Surface energy
  - Microporous beads

- Inorganic polymers - uniform sedimentation (particles grown from sols)

- Gas-phase polymerization
  - Fundamental studies of polyolefins
  - Distribution of catalysts
  - Limited catalyst attrition
  - Low gas velocities accessible

- Flocculation
  - Mechanism (flocculation versus settling)
  - Stabilization

- Ultrathin films - formation of Langmuir-Blodgett films

- Mechanics of repairing composites in space
  - Adhesion
  - Pressurization
  - Aggressive environment

- Manufacture of large structures in space

- Non-Newtonian rheology
  - Multiphase dispersions
  - Density-induced changes
  - Concentration effects
  - Particulate-filled emulsions

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15. Supplementary Notes

16. Abstract

A one-day, interactive workshop considering the effects of gravity on polymer materials science was held in Cleveland, Ohio, on May 9, 1985. Selected programmatic and technical issues were reviewed to introduce the field to workshop participants. Parallel discussions were conducted in three disciplinary working groups: polymer chemistry, polymer physics, and polymer engineering. This proceedings presents summaries of the workshop discussions and conclusions.

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